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COPPER SULPHATE TREATMENT OF ST. PAUL, MINNESOTA, WATER SUPPLY

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WITH INTRODUCTION BY

Garrett O. House

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Water supplied the city of St. Paul is obtained from a series of large and small lakes extending north from the city limits for twenty miles, shown on map page 579. Lake Vadnais, being nearest the city, is used as a natural distributing reservoir, water from the lakes farther north is conducted into Vadnais Lake in quantities sufficient to replenish the water drawn for the city's supply.

In a report to the Board of Water Commissioners in 1915, Mr. Allen Hazen says regarding the quality of the water supplied St. Paul:

> The water in the lakes exposed to the sunlight supports a vigorous growth of microscopic and other plants during the summer. These serve in part as food for larger organisms and animals and, in part, decompose in the water or add to the mud upon the bottoms of the lakes.
>
> As a result of these conditions, the water is subject to disagreeable tastes and odors resulting from the growth and decay of the organisms. It also frequently contains small organisms visible to the naked eye and not agreeable to those who use the water.
>
> The catchment area is occupied by a scattered rural population, with only one small village, Centerville, and the danger of pollution of the water under all the existing conditions is not very great.
>
> With water of this kind, full and accurate knowledge of what growths of organisms are taking place in the reservoirs and lakes is of fundamental importance. This can only be secured by having a suitable laboratory upon the ground. Many of the organisms are fragile and will not bear shipping. Experience shows that samples cannot be sent to an analyst even a few miles away and secure adequate records. A laboratory should be established at Vadnais Lake, in charge of a man who thoroughly understands the organisms that grow in lake waters, and examinations should be made of the waters of the lakes and records kept of all the conditions affecting the quality of the water.

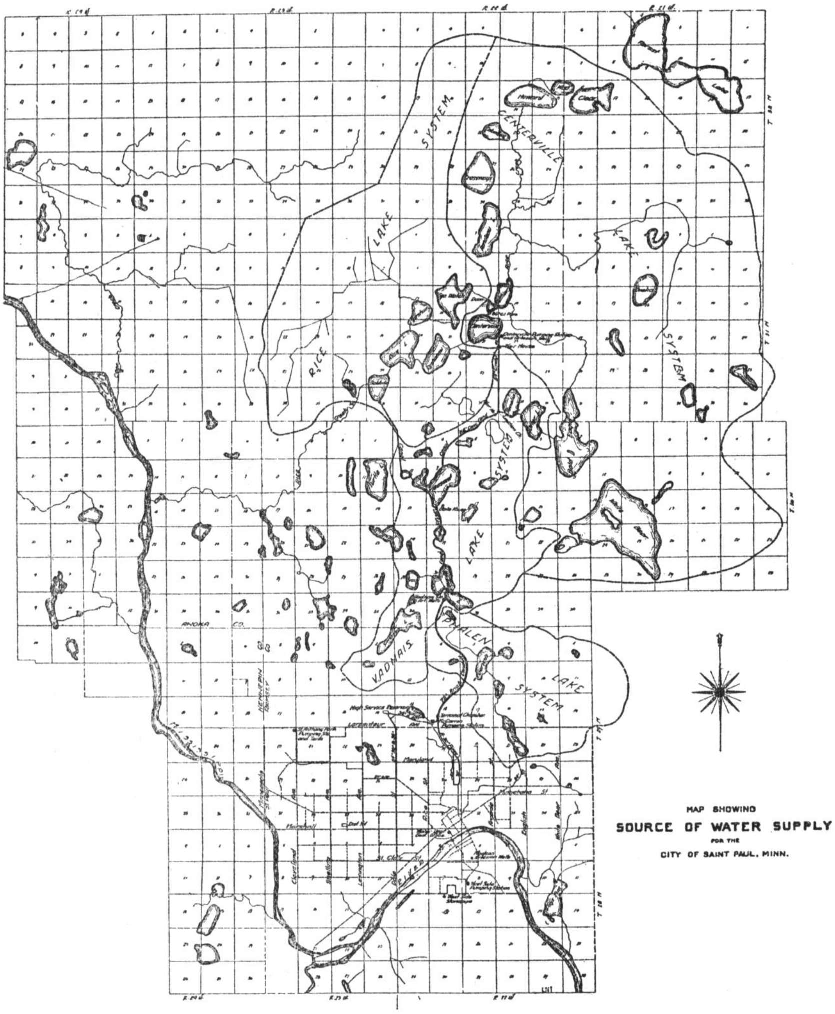

MAP SHOWING
SOURCE OF WATER SUPPLY
FOR THE
CITY OF SAINT PAUL, MINN.
RICE LAKE SYSTEM
CENTERVILLE LAKE SYSTEM
VADNAIS LAKE SYSTEM
PHALEN LAKE SYSTEM
ANOKA CO.
HENNEPIN COUNTY

FIG. 1

> In connection therewith, the use of copper sulphate, tried somewhat experimentally, but successfully, by the department in 1914, may properly be continued and extended. Considerable assistance may be obtained from it with skillful use, and it is particularly important that this should be used to produce all the benefit of which it is capable during the period before filters are installed.
>
> Copper sulphate was applied last year to the water at the outlet of Pleasant Lake, and the water improved by its use went into Vadnais Lake at a point so remote from the intake that little effect was noticed in the quality of the water supply. In carrying out the matter again, it will be better to treat the water in Vadnais Lake itself. This treatment is customary and can be carried out with safety. It must be done, however, under skilled supervision and with care. It is best to kill the objectionable growths as they start and before the organisms have developed so as to form a heavy mass. Applying copper sulphate at the wrong time has sometimes had the result of filling the water with the dead and decaying carcasses of organisms, and has had an effect quite different from that which was intended. The process is useful and helpful, but it requires a high degree of skill to obtain the full measure of benefit from it.

Following Mr. Hazen's recommendations, Prof. N. L. Huff of the Department of Botany of the University of Minnesota, was, in June, 1915, engaged to make a microscopical study of the water supplied the city and supervise its treatment with copper sulphate; to facilitate this work a laboratory was established at Vadnais Lake. The detailed report which follows will, it is hoped, be of benefit to departments and individuals who have a similar problem to deal with.

The cost of each of the three general treatments made was $17.50 for labor and $180 for material.

The efficiency of the treatment is plainly indicated by the materially reduced number of complaints of bad taste or odor from consumers.

Copper sulphate as an algicide is now recognized by water departments everywhere. In a large number of cities where algae or other microörganisms have become troublesome in city water supplies, copper sulphate has been used with success. In many respects its use is beyond the experimental stage. If used in sufficient quantities and under proper conditions it will, without doubt, destroy practically all of the objectionable vegetable growths. The minimum amount necessary to destroy each organism, the particular stage in the life of the individual when the effects of the

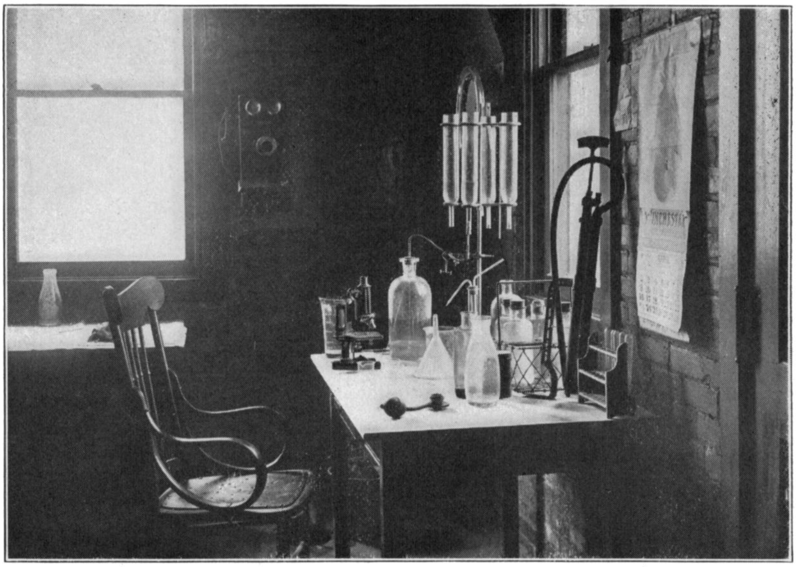


FIG. 2. LABORATORY AT VADNAIS LAKE

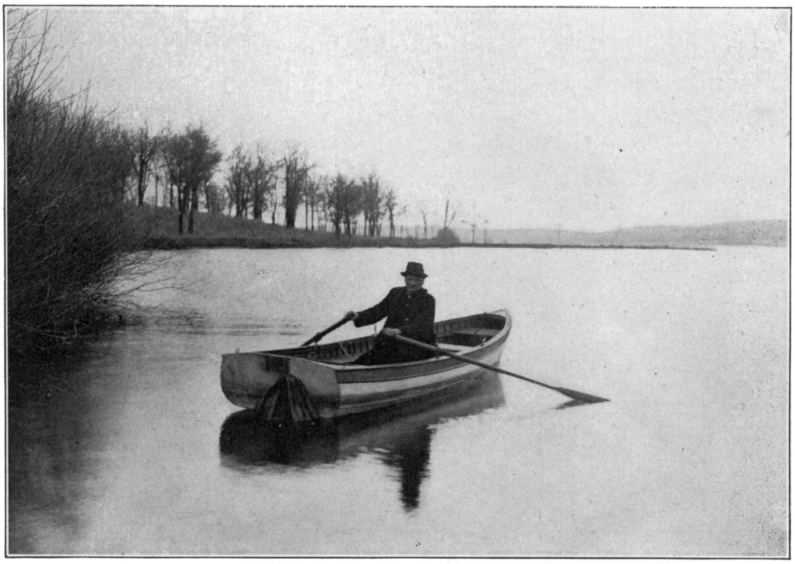
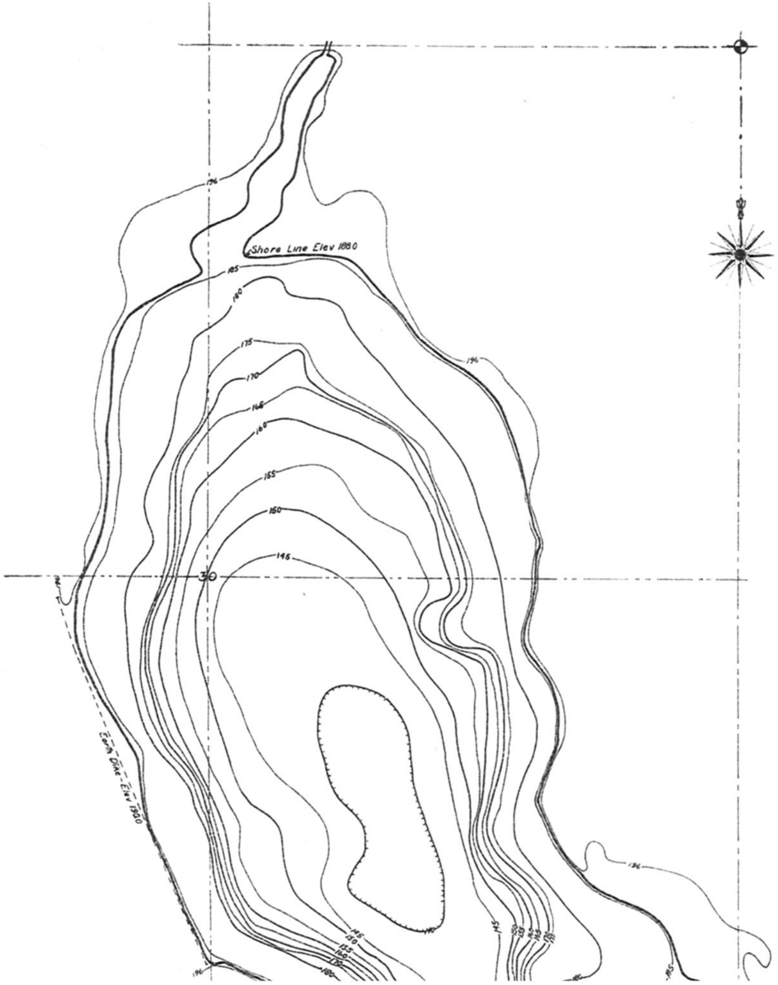


FIG. 3. BOAT TREATMENT

MAP SHOWING
CONTOURS OF VADNAIS LAKE
ST PAUL MINN. WATER SUPPLY



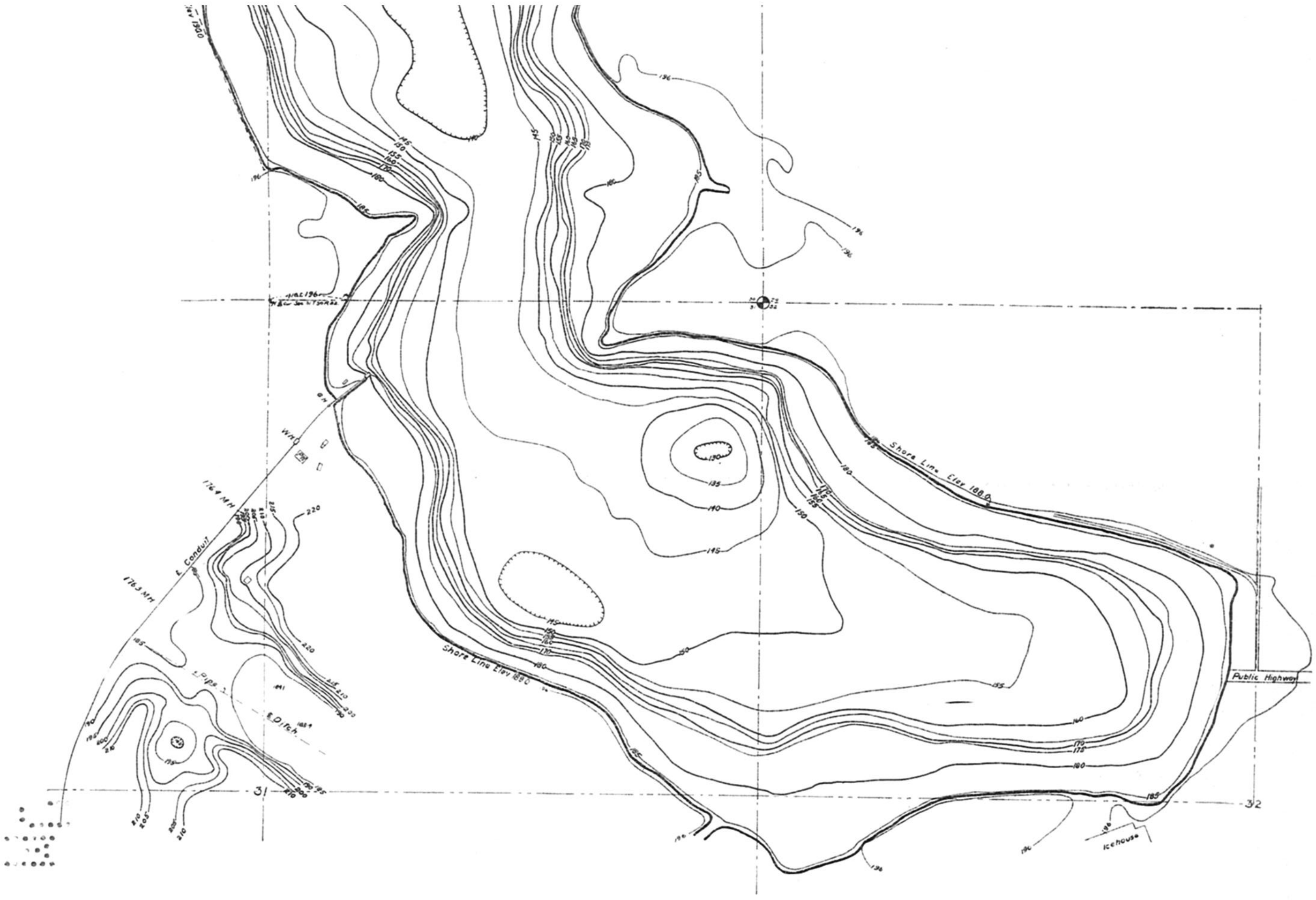

Shore Line Elev 188.0
Shore Line Elev 188.0
Public Highway
Icehouse
E Conduit
E Pipe
E Ditch
176.4 MH
176.3 MH
31
32
130
135
140
145
150
155
160
165
170
175
180
185
196
200
205
210
215
220

FIG. 4

copper are most deadly, and the exact conditions under which the treatment is most effective for the various organisms, these are some of the problems that are much in need of further study. Each place where the treatment is made offers its special problems. The particular organism causing the trouble may differ in different places. The size and depth of the lake or reservoir to be treated; the temperature of the water; the presence of organic and mineral substances in the water; the size and general nature of the watershed; all these and many other points should be considered when trying to eliminate or control the microörganisms of a water supply system. The experience of others working under similar conditions is always helpful and may be extremely valuable. The number of detailed reports, however, that might be of value to those who wish to make such treatments, is surprisingly small. In many places where treatments have been made the results of the treatment have never been published. In other places the general results are given, but of the exact organisms present, the effect of the treatment upon each organism, the conditions under which treatments were made and other important points little or nothing is said.

The object of this paper is to set forth the effect upon several microörganisms of a series of copper sulphate treatments in Vadnais Lake during the summer of 1915. The lake was given three treatments during the summer, the first June 14, the second July 12, and the third August 27. Besides these general treatments small quantities of copper sulphate were dissolved several times during the summer, in very limited regions along the shore where some particular organism began to accumulate. The study of the organisms was started on June 11, three days before the first treatment, and continued until the lake was frozen over December 11, three and one-half months after the last treatment. Unless otherwise stated, the samples which furnished the material for the following results were collected just above the weir where the water leaving Vadnais Lake enters the conduit leading to McCarron Pumping Station.

Vadnais Lake is located 7 miles north of the city of St. Paul, and has for the most part high well drained shores. The lake is about 1¾ miles in length and ⅓ of a mile in width, covering about 358 acres. Its greatest depth is 57 feet, and the average depth for the entire lake is 27 feet. With the water at the ordinary level, the capacity of the lake is approximately 3,240,000,000 gallons.

The copper sulphate treatments were carried on by the Bureau of

Water, Department of Public Utilities, of the city of St. Paul, for the purpose of destroying the microörganisms which were objectionable in the city water supply. The writer wishes to acknowledge his indebtedness to this Bureau, and especially to Mr. G. O. House, General Superintendent, and Mr. R. L. Smith, Principal Assistant Engineer, without whose assistance and coöperation the work would not have been possible.

The use of copper sulphate for eradicating algae and other objectionable organisms from storage reservoirs and city water supplies, has been practiced for more than ten years. The discovery by George T. Moore, in 1901, of the effect of copper sulphate upon Spirogyra in watercress beds, and the publication by Moore and Kellerman of the Bureau of Plant Industry, U. S. Department of Agriculture, of a couple of bulletins[1] in 1904 and 1905, on the effect of copper sulphate upon bacteria and algae in water supplies, led to quite an extensive use of copper sulphate throughout the country. As early as 1905 the *Journal of New England Water Works*[2] gives a table, compiled from those who had used the copper sulphate treatment, showing the results of many experiments. This table contains definite information on several points, the size of the reservoir treated, the strength of the treatment, the name of one or more organisms causing trouble and the general effect of the treatment upon the organism or organisms causing the trouble. The report covers some 27 cities, representing more than a dozen different states. Both the strength of the treatment and the organism causing trouble varied a good deal in different places. The strength of the treatment was in most cases somewhere between 1 to 8,000,000 and 1 to 1,000,000, and the alga most frequently reported as causing trouble, was Anabaena. The results were almost uniformly favorable, destruction of the troublesome algae and disappearance of all disagreeable taste and odor from the water in a few days. In about one-half the cases cited the algae appeared again the same season, one, two, or three months after the treatment. In several cases where the algae did not occur again during the same season, the treatment was made rather late in the season, in August, September, October, or even as late as November, and the lateness of the season was doubtless largely responsible for their inability to get a second start.

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[1] U. S. Dept. of Agr. Bur. of Plant Ind. Bull. 64, 1904, and Bull. 76, 1905.

[2] *Jour. N. E. W. W. Asso.*, vol. 19, 1905, p. 582.

Caird,[3] one of the early workers with the copper sulphate treatment, obtained some interesting results in treatment of reservoirs under normal conditions in 1904 and 1905, and gives in his reports the effect of several treatments of different strength, upon several algae common in the reservoirs treated.

Lovejoy's[4] experiments at Louisville in connection with filter troubles in 1909–1910 are especially interesting. He found in 1909 when several organisms were clogging the filters that by using 14 pounds of copper sulphate per million gallons of water, the filter runs were increased from two hours to the normal of twelve or fourteen hours within three days after treatment. In August, 1910, when filter troubles were caused largely by Synedra and Melosira he found that a treatment of 1.67 parts per million, increased the filter runs from about two hours to a normal of thirteen hours within three days after treatment.

In many places the organisms to be destroyed have been determined before treatment, and the effects of the treatment upon one or more abundant organisms noted in a general way, yet in a very large number of cases where the treatment has been used not even a microscopic examination of the water has been made and the species of algae present or causing the trouble were unknown. Definite and detailed reports giving the conditions under which treatments were made, the strength of the treatment, followed up by the results of the treatment upon various organisms, as can be determined only by regular and frequent microscopic counts of organisms present in the treated water, have in most cases been sadly neglected. The following paper shows the effect of copper sulphate upon several organisms common in Vadnais Lake.

The method used for determining the number of organisms is known as the Sedgwick-Rafter method, and may be described briefly as follows:

A sample consisting of 500 cc. of water is placed in a cylindrical funnel and filtered through a layer of fine sand[5] about 2 cc. in thickness. This sand strains out practically all organisms. When only 5 cc. of water remain unfiltered, the process is stopped, the sand and water are emptied into a small beaker, and the sand thoroughly rinsed with this water which is then carefully drained off into a clean beaker. The sand is rinsed again, this time with 5 cc. of distilled water, which removes practically all remaining organisms from the sand. The water used for this second rinsing is now mixed with that used for the first, and this is decanted two or three times to free it from all sand particles. This 10 cc. is thoroughly mixed with a pipette, and while the organisms are still uniformly distributed throughout the mixture, a single cubic centimeter is removed and placed in the Sedgwick-Rafter counting cell, for microscopic examination. The Sedgwick-Rafter cell is exactly 1 mm. in depth, and by proper adjustment of the drawtube of the microscope, a Whipple eyepiece micrometer may be made to cover exactly 1 square mm. This will give as a field for counting, exactly 1 cm., and makes the computation very simple. Usually ten counts were made from each sample though when organisms were greatly reduced in numbers so that many cubic millimeters of the concentrated sample did not contain a single organism, one hundred such counts were made, in order to reduce as much as possible, the error arising from the difficulty of picking out typical areas for the count. From the number of organisms found in a given volume of this concentrated sample it is a very simple matter to compute the number in the water as it is found in the lake.

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[3] Caird, Jas. M., Copper Sulphate Treatment for Algae at Middletown, N. Y. *Eng. News*, Jan. 12, 1905, p. 33. Also Copper Sulphate Results, *Proc. Am. W. W. Assoc.*, 1906, p. 249.

[4] Lovejoy, W. N., Filter Troubles Caused by Micro-organisms at Louisville. *Eng. Rec.*, vol. 62, 1910, p. 664.

[5] The sand used for filtering was a medium fine sand ranging from 0.1 mm. to 1 mm. in diameter, though most of it was less than 0.3 mm. in diameter.

On account of the great variation in size and form of different organisms, and the consequent impossibility of making comparisons between different organisms that would really mean anything, the figures used in the charts or diagrams for indicating the quantity of organisms present, do not refer to the actual number of individuals or colonies of a given organism, but to standard units, a system of measurement suggested by Whipple for convenience in comparing the various forms. The standard unit is represented by a square 20 microns on a side (1 micron equals 0.001 mm.). In computing the number of standard units in a given individual or colony, an attempt has been made to approximate the volume rather than the area of the upper surface. In the majority of cases where individuals are quite uniform in size, the number of individuals was multiplied by a number found to be the average size for that species. In other cases, however, where there was great variation in size, as in filamentous forms, and forms growing in colonies of an indefinite size, the size was computed separately for each occurrence of the species in the part of the sample counted.

The following lists show the average size in standard units, of several organisms occurring commonly in the waters of Vadnais Lake:

Diatomaceae (Diatoms)

	size
Asterionella	0.5
Synedra pulchella	1.0
Fragilaria	0.25
Melosira	0.25
Cyclotella	1.0
Stephanodiscus	15.0
Synedra ulna	15.0
Epithemia	4.0
Tabellaria	1.0
Navicula	1.0
Pleurosigma	10.0
Amphora	15.0
Nitzschia	0.1
Rhizosolina	0.5
Eunotia	3.0

Protozoa (Simple animals)

Ceratium	10.0
Dinobryon	0.5
Peridinium	6.0
Vorticella	3.0
Epistylis	5.0
Trachelomonas	1.0
Glenodinium	6.0
Paramaecium	20.0
Coleps	3.0
Phacus	3.0
Mallomonas	2.0
Coelomonas	3.0
Uroglena*	
Synura*	

Chlorophyceae (Green Algae)

	size
Eudorina	10.0
Pandorina	3.0
Pediastrum	10.0
Staurastrum	3.0
Cosmarium	5.0
Closterium	20.0
Gloeocystis	5.0
Scenedesmus	0.5
Volvox*	500.0
Raphidium	1.0
Gonium	5.0
Dictyosphaerium*	5.0
Coelastrum	1.0
Docidium	40.0
Dimorphococcus	1.0
Micrasterias	10.0
Richteriella	0.1
Spirogyra*	
Hyrodictyon*, and all other filamentous algae.	

*Cyanophyceae** (Blue-green Algae)

Anabaena*
Clathrocystis*
Coelosphaerium*
Rivularia*
Aphanocapsa*
Aphanizomenon*

---

* The size of the colony or filament in these forms was estimated for each occurrence in the part of the sample examined, as their variation or indefinite size made averages unreliable.

The method of distributing the copper sulphate in the lake was that which has commonly been employed in such treatments. About

50 pounds of the crystals were placed in a burlap sack, this tied to the stern of a boat and the boat rowed back and forth until the sulphate was dissolved, care being taken to distribute systematically, and as uniformly as possible. In addition to the rowboats which were used near the shore, a small motorboat with a bag of copper sulphate attached to either side, was used for distributing in the central part of the lake.

The following chemical analyses were made by Mr. V. H. Roehrich, Director of the Bureau of Municipal Testing Laboratories, Department of Public Utilities, of the city of St. Paul:

Sanitary Analysis:	*parts per million*
Suspended matter	3.00
Total solids (dissolved)	165.00
Chlorine	6.00
Nitrogen as free NH_3	0.086
Nitrogen as albuminoid NH_3	0.494
Nitrogen as nitrites	0.001
Nitrogen as nitrates	0.480
Oxygen consuming power	2.700

Boiler Analysis:	*parts per 100,000*
Total solids (dissolved)	16.50
Total hardness	13.30
Sulphate hardness	0.20
Total alkalinity	13.50
Alkali salts	3.00
Sodium carbonate	0.00
Foaming rate	Very good
Incrusting rate	Very good

The following figures from Mr. Roehrich's report on the determination of copper in water taken from the terminal chamber at McCarron Pumping Station, four miles below Vadnais Lake, show how quickly the copper disappears from the water after a copper sulphate treatment:

About 0.03 parts of copper per million was introduced in Vadnais Lake at 11.00 a.m. on June 14, 1915.

	parts of copper per million
Sample No. 1 taken June 14, 1915, at 5.30 p.m.	0.0005
Sample No. 2 taken June 15, 1915, at 2.30 p.m.	0.0175
Sample No. 3 taken June 16, 1915, at 5.30 p.m.	0.0015

As has been stated by Moore and others it is impossible to give definite figures for the amount of copper sulphate necessary to eradicate a given organism, for several factors must be considered. The temperature of the water, the amount of organic matter present, as well as the presence or absence of various chemical substances such as calcium, magnesium, oxygen and carbon dioxide, etc., probably have their effect upon the amount of copper sulphate necessary to destroy a given organism, and just what part each of these factors plays in the action of the copper sulphate upon algae, has not yet been determined. The figures, therefore, representing the quantity of copper sulphate necessary to eradicate various organisms vary a good deal with different observers. Moore and Kellerman (U. S. Dept. of Agr., Bureau of Plant Industry, Bull. 76, 1905) give a table based in part upon treatments in reservoirs under normal conditions; Whipple (*The Microscopy of Drinking Water*, p. 255, 1914) gives a similar table, based largely upon Kellerman's figures. These are perhaps as reliable as any that have been compiled. The results of the treatment of Vadnais Lake, however, are so different from the results given by either of these observers that it seems well worth while to direct our attention to a few of the organisms, and their response to the copper treatment here. One of the most interesting organisms in this connection is Synedra pulchella. Moore and Kellerman suggest for the eradication of Synedra the use of one part of copper sulphate in 600,000 parts of water. On June 14, the time of the first treatment with copper sulphate, there were present in the water at the weir as it enters the conduit leaving Vadnais Lake, 3420 individuals of Synedra pulchella per cubic centimeter of water. The treatment[6] given was about one part of copper sulphate to 12,000,000 parts of water, and by June 25, the number of Synedra had dropped from 3420 to 1116 per cubic centimeter. Other organisms present were reduced in a similar manner, but before a month had elapsed, practically all organisms were rapidly increasing again, and it was decided to give a second treatment. This time it was thought advisable to give a heavier treatment so one part of copper sulphate was used for each 10,000,000 parts of water in the lake. This treatment was given on July 14, and Synedra had reached the very high figure of 7720 individuals per cubic centimeter of water. The results of the heavier treatment[7] were surprising. Each day showed a marked reduction in the number of Synedra, and in ten days time the number had dropped from 7720 to less than 100 individuals per cubic centimeter. For about four weeks following this, Synedra remained inactive, running from 12 or 15 per cubic centimeter to 100 per cubic centimeter, but not until about August 20 did they begin to show signs of rapid increase in numbers again. This remarkable reduction was secured by a treatment of one part in 10,000,000, or 6 per cent of that suggested by Moore and Kellerman as effective for Synedra. It is true that this treatment did not result in the complete destruction of Synedra. Whether this was due to certain hardy individuals that were able to withstand a treatment of that strength, or to the fact that the copper sulphate was not distributed with absolute uniformity, and some on this account escaped the treatment, we cannot say. With these organisms pouring into the lake, however, in great quantities as they were here through the waters of the inlet, it is doubtful if a treatment of several times this strength would have been effective for more than five or six weeks.

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[6] The amount of copper sulphate used for the entire lake in this treatment was 2250 pounds. The capacity of the lake is 3,240,000,000 gallons, and this would mean about 1 pound of copper sulphate for 1,400,000 gallons of water. Expressed in pounds, we have 2250 pounds of copper sulphate to 27,000,000,000 pounds of water, or approximately one part of copper sulphate to 12,000,000 parts of water.

[7] For this treatment 2700 pounds of copper sulphate were used for the 3,240,000,000 gallons of water in the lake. This would give approximately 1 pound of copper sulphate for 1,200,000 gallons of water, or one part in 10,000,000.

Among other organisms responding to a lighter treatment than that suggested by Moore and Kellerman, may be mentioned Eudorina and Pandorina for which above authors recommend the use of one part of copper sulphate to 100,000 parts of water, and Stephanodiscus for which they recommend one part of copper sulphate to 250,000 parts of water. Eudorina having 100 standard units per cubic centimeter of water practically disappeared within five days after above treatment. Pandorina with 162 standard units per cubic centimeter of water dropped in eight days to an occasional single individual in a sample, and it was more than a month before either of these two organisms began to show any material increase in numbers. Stephanodiscus, which for nearly three weeks had maintained an average of 140 standard units per cubic centimeter of water, almost completely disappeared within a week after the second treatment, and only an occasional individual was found for several weeks following. Late in August a slight increase was noticed but the third copper treatment was given about this time and that put a check upon its development, and for more than another month it was unable to establish itself again. As samples were taken at several points in the lake, also from different depths in the deepest part of the lake, both before and after treatment, and compared with samples taken daily at the weir, it was found that these figures may be considered as representing not the varying conditions of small local areas, but are essentially true for the entire lake surface, as well as for all depths down to 20 feet or more below the surface. Below a depth of 20 or 25 feet these and other algae were comparatively rare all summer.

About August 20, or more than a month after the second treatment, the organisms, especially Synedra, began to show great increase in numbers. In seven days the total number of organisms increased from 100 standard units per cubic centimeter, to 3952 standard units per cubic centimeter. A third treatment of copper sulphate August 27, of the same strength as the second (1 to 10,000,000), given more than a month before, put a sudden check upon the increase, and brought them down, a little more slowly than before, but by the 14th of September they were again below 100 standard units per cubic centimeter, and remained comparatively low for about another month, many of them not increasing again during the entire season.

During the summer months the water in the bottom of the lake has a temperature of from 10 to 20°F. lower than that of the surface. The maximum temperature for the bottom of the lake was about 59°F., which was reached late in July. The surface temperature was sometimes as high as 78°F. The colder heavier water of the greater depth is not mixed with the lighter water above by ordinary surface disturbances, and therefore becomes quite stagnant during the several months when the surface water is comparatively warm. During September, however, with the short days and cooler nights, the water of the surface of the lake begins to cool and continues gradually until the lake freezes over in December. The water cools of course from the surface, and whenever the surface becomes cooler than the water of the bottom, this cooler, heavier surface water settles to the bottom, and the warmer water of the bottom rises to the surface. This circulation or overturning process will continue for several weeks until the temperature of all of the water in the lake has lowered to 39.2°F., where it reaches its maximum density. In Vadnais Lake in 1915 this overturning process began about September 24, and continued until about November 25. In the early stages of this circulation, some organisms, especially diatoms, were more abundant at the bottom, 50 feet below the surface, than they were at the surface. During the greater part of the circulation period, however, the organisms were distributed nearly uniformly from surface to bottom of the lake. This is very different from their distribution during the summer months when the water near the bottom of the lake was stagnant, and organisms in large numbers were never found below a depth of 20 or 25 feet.

The great increase of one species of diatom, Stephanodiscus niagarae, during the period of circulation was not entirely unexpected. On the contrary it seems a little strange that some of the other diatoms so common during the summer did not show a similar increase. It is generally known that diatoms increase during the period of circulation of water that follows a period of stagnation. Definite reasons for this phenomenon can not be given until we know the amounts of various materials, organic and inorganic, they require for food, as well as the conditions of temperature light, and air most favorable to their growth and reproduction. It is known that some species of diatom are saprophytic,[8] and it is probable that many of them are able to utilize albuminous or similar nitrogenous compounds from the water in which they live. Dr. Maximilian Marsson[9] is authority for the statement that they can absorb carbon compounds from dissolved organic matter, also organic nitrogen, and when carbonic acid is excluded from the water in which they live, they can digest diluted volatile fatty acids, amido-acids, urea, peptone and other substances. Karsten[10] found that certain diatoms not normally saprophytic could be made so by the proper cultivation in nutrient media. With this information on the food habits of diatoms, it is not difficult to see why the nutritive conditions in a lake like Vadnais are unusually favorable for these forms during the circulation period following several months of stagnation. The following theory for the explanation of the occurrence of maximum growths of diatoms during the circulation period following stagnation in deep lakes is offered by Whipple,[11] and is well worth our attention here: With the decay of organic matter in the bottom, during the stagnation period, the water near the bottom undergoes great changes. Oxygen is exhausted, ammonia and other compounds, both organic and inorganic, increase and are dissolved in the water. With the upward currents during circulation, not only is this water, rich in food materials, carried upward where conditions for diatom growth are more favorable, but the spores, and diatoms themselves which in their inactive condition at least are heavier than water and have lain dormant in the mud of the bottom, where light is too weak, and other conditions are unfavorable for growth, these also are carried upward where light and air conditions are favorable, and with the abundant nourishment now present, they multiply with great rapidity. This perhaps accounts for the high point reached by some of the organisms, especially Stephanodiscus, late in the season while this autumnal shifting of waters was going on.

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[8] West, *The British Freshwater Algae*, 1904, p. 264.

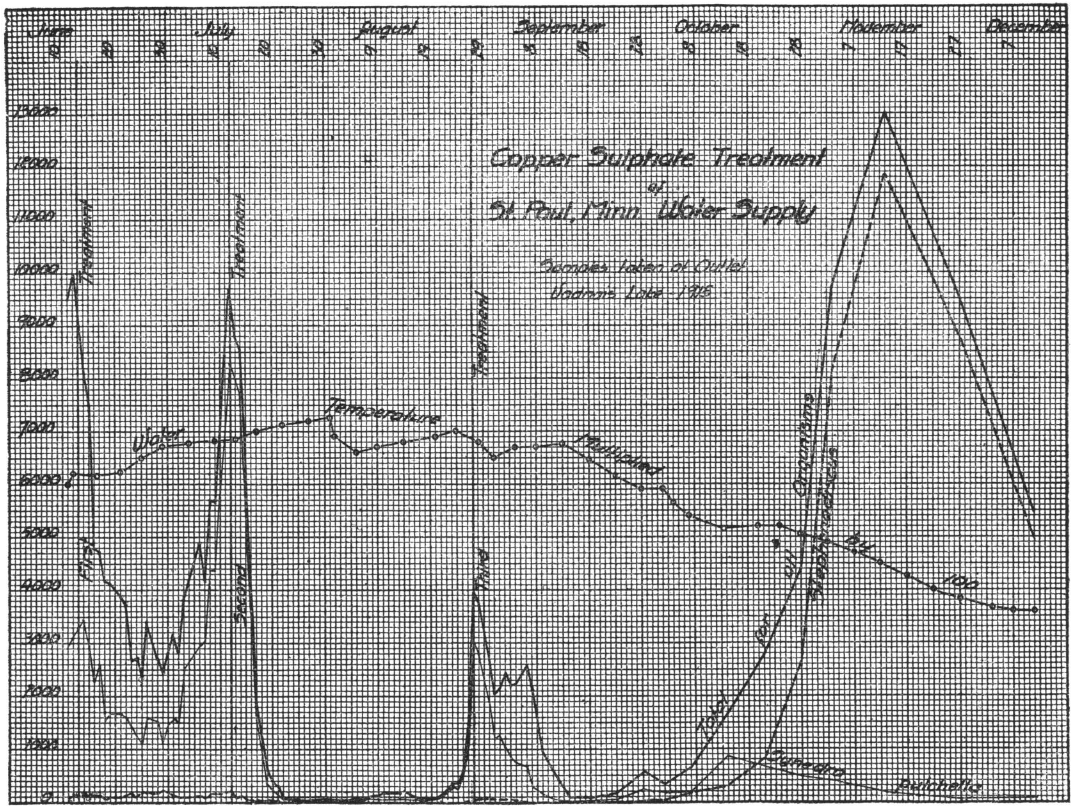
[9] *Eng. News*, Aug. 31, 1911, vol. 66, p. 246 (translation by Emil Kuichling).

[10] Karsten, G., Ueber farblose Diatomeen, *Flora* 89, 1901, p. 404.

[11] Whipple, *The Microscopy of Drinking Water*, 1914, p. 169.

A brief study of the accompanying charts or figures will give a much clearer idea of the effect of copper sulphate upon the various organisms than can be given perhaps in any other way. The variation in the total of all organisms from June 11 to December 11, is shown in curve 1. This chart also shows the variation of the two diatoms, Synedra pulchella and Stephanodiscus niagarae, the two most abundant organisms, as well as the changes in water temperature for the same period. On June 14, the day of the first treatment with copper sulphate, the total number of organisms per cubic centimeter of water was 8100 standard units. Of these, 3420 standard units were due to Synedra pulchella. The remaining 4700 units were made up of other diatoms, green algae, bluegreen algae, and protozoa, the numbers of which are brought out in other figures. The treatment consisted of about one part of copper sulphate to 12,000,000 parts of water. It was responded to by most of the forms but was not nearly so effective as the slightly heavier treatments given later. Within less than two weeks the total number of organisms had dropped to 2400 with about 1100 standard units of Synedra. Early in July, Synedra began to show a rather rapid increase in numbers, and by July 12, had reached 8260 standard units per cubic centimeter, bringing the total number of organisms per cubic centimeter up to approximately 9700 standard units. A second treatment of one part of copper sulphate to 10,000,000 parts of water brought very decided and satisfactory results. Within ten days after the treatment the total number of organisms dropped from 9700 to less than 100 per cubic centimeter, where they remained for more than four weeks.

The rate of increase or multiplication in some of the diatoms is interesting, and a glance at the chart (curve 1) will show how very rapidly they increase when once conditions become favorable for their growth. The following figures for Synedra pulchella show how it increased in eight days under normal conditions in Vadnais Lake:


Copper Sulphate Treatment
of
St. Paul, Minn. Water Supply
Samples taken at Outlet
Vadnais Lake 1915
June
July
August
September
October
November
December
10
20
30
10
20
30
9
19
29
8
18
28
8
18
28
7
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27
7
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Treatment
Treatment
Treatment
First
Second
Third
Water
Temperature
Multiplied
by
100
Total
per
cc
Organisms
Stephanodiscus
Synedra
Pulchella

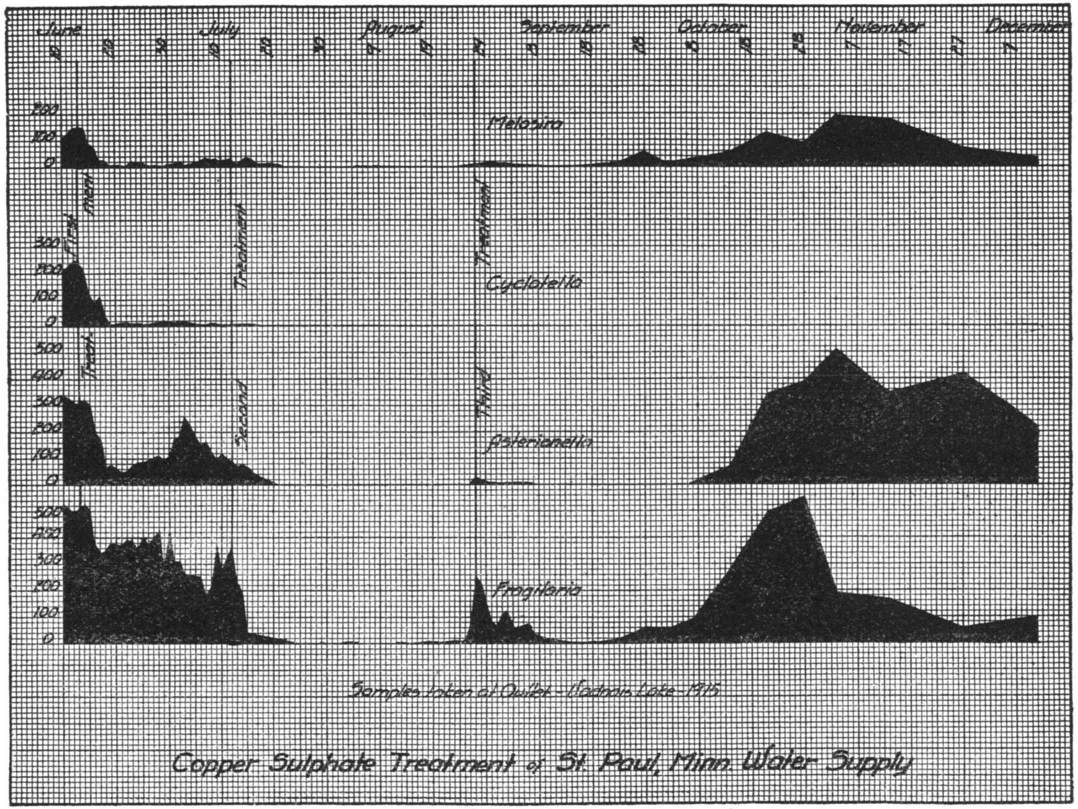
Curve 1

	Individuals per cubic centimeter
August 19	46
August 20	80
August 21	114
August 23	300
August 24	225
August 25	520
August 26	1,080
August 27	3,020

Judging from these figures Synedra may, under favorable conditions double its number in about twenty-four hours, and at this rate of increase, a comparatively small number surviving after the treatment, or entering the lake through the inlet, after the treatment, will be sufficient to replenish the lake in a very short time.

On August 27, with the total number of organisms about 4000 standard units per cubic centimeter, a third treatment of copper sulphate of the same strength as the second (1 to 10,000,000) was given the entire lake. The reduction of organisms that followed was similar to that of the second treatment, but required about 18 days to bring the number below 100 standard units per cubic centimeter. Synedra and some of the other forms responded much as before, but Eudorina and Pandorina continued to increase in numbers for several days after the treatment and this accounts for the longer time required to bring down the total number to its former position. For more than a month following this reduction in numbers the total number of organisms did not rise above 1000 standard units per cubic centimeter. The latter part of October, however, with the circulation following the stagnation period of the summer months, some of the diatoms showed quite an increase. Most notable among these was Stephanodiscus niagarae which continued to increase until about the middle of November when it reached the very high number of 11,850 standard units per cubic centimeter. When the water temperature of the lake had lowered to 39.2°F. the maximum density for water, and the circulation ceased, Stephanodiscus began to show a reduction in numbers, and by December 11, about the time when the lake became frozen over for the winter, this organism had been reduced to about 4920 standard units per cubic centimeter, and was still going down very rapidly.

The response of four other diatoms to the copper sulphate treatment is shown in curve 2. These four, Melosira granulata, Cyclo-


June
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August
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29
September
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October
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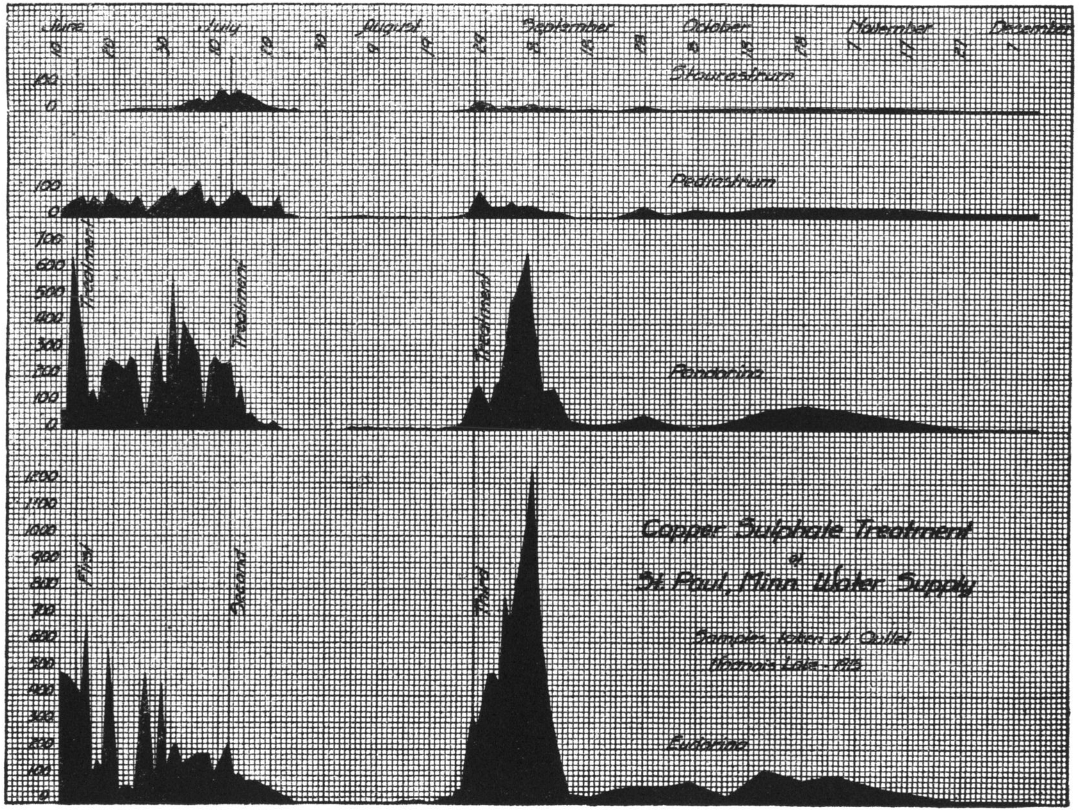
28
November
7
17
27
December
7
200
100
0
Melosira
First Treat-ment
Second Treatment
Third Treatment
300
200
100
0
Cyclotella
500
400
300
200
100
0
Asterionella
500
400
300
200
100
0
Fragilaria
Samples taken at Outlet - Vadnais Lake 1915
Copper Sulphate Treatment of St. Paul, Minn. Water Supply

CURVE 2

tella comta, Asterionella formosa, and Fragilaria capucina, were the only diatoms, aside from the two mentioned above, that occurred commonly in the main body of the lake. The first copper treatment resulted in the complete elimination of Cyclotella comta for the season. Melosira, which was greatly reduced by the first treatment, was practically eliminated by the second, not to occur in large numbers again until late in September, after the autumnal circulation had begun. Asterionella and Fragilaria were greatly reduced by the first treatment, and practically eliminated by the second treatment. Both of these had made a fair start, however, late in August, but the third treatment cut them down at this time and not until the autumnal circulation of late September and October did they reëstablish themselves in even fairly large numbers. These, like Stephanodiscus, were greatly reduced as soon as the autumnal circulation had ceased, and before the lake had started to freeze over.

The several species of green algae common in Vadnais Lake vary a good deal in their sensitiveness to copper sulphate. Spirogyra, for example which was quite common, from 500 to 600 standard units per cubic centimeter at the time of the first treatment, was entirely eliminated within three or four days after the treatment. Just before the second treatment it occurred again in small quantities, there being from 100 to 150 standard units per cubic centimeter. With the second treatment it disappeared completely and not even a trace of it was found in the main body of the lake the remainder of the summer. Some other forms, however, especially Eudorina and Pandorina, were found to be at times more resistant. These two forms, as is shown in curve 3, were running from 300 to 400 standard units per cubic centimeter at the time of the first treatment. They showed a decided decrease in numbers shortly after the treatment but continued to oscillate a good deal between 50 and 300 standard units per cubic centimeter until after the second treatment, July 12. With this treatment both of these forms and two others that had occurred in smaller numbers, namely Pediastrum and Staurastrum, were practically eliminated, none of them running higher than from 1 to 10 standard units per cubic centimeter until late in August. The third treatment, August 27, was not responded to by Eudorina and Pandorina as quickly as the second treatment had been. Instead of decreasing at once as they had done before, they continued to increase slowly in numbers for about two weeks after the treat-


June
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7
17
27
7
Staurastrum
100
0
Pediastrum
100
0
Pandorina
700
600
500
400
300
200
100
0
Treatment
Treatment
Treatment
Eudorina
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
First
Second
Third
Copper Sulphate Treatment
of
St. Paul, Minn. Water Supply
Samples taken at Outlet
Vadnais Lake - 1915

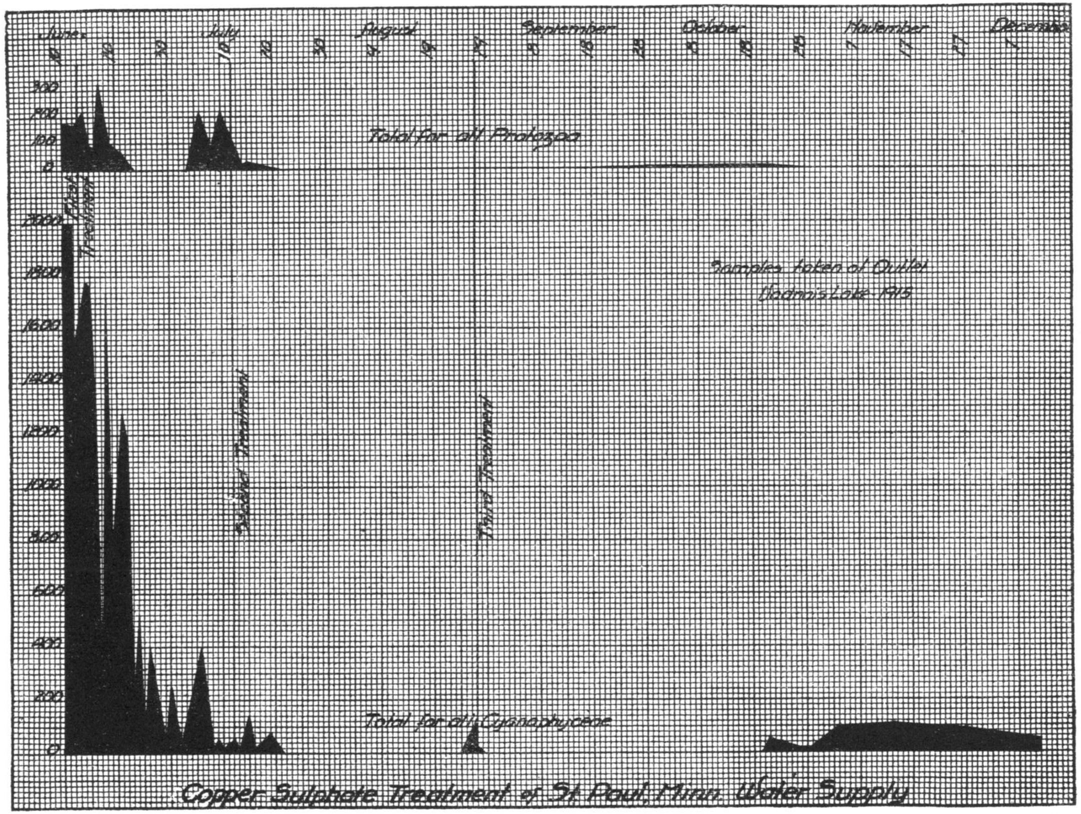
Curve 3

ment. They were finally forced to succumb, however, and after about two weeks of stubborn resistance, Eudorina with 1,200 and Pandorina with nearly 700 standard units dropped rather suddenly to less than 100 standard units per cubic centimeter each. They did not rise materially again during the season.

Most of the bluegreen algae are very sensitive to copper sulphate. At the time of the first treatment they were running from 1500 to 2000 standard units per cubic centimeter (curve 4), Anabaena oscillarioides being responsible for the greater part of this. The first treatment cut the number down to an average of about 100 standard units per cubic centimeter, and the second treatment eliminated them almost completely. About the time of the third treatment they increased to 100 standard units per cubic centimeter, but were completely eliminated by this treatment, and scarcely a trace of them occurred again until late in October when Aphanizomenon appeared, running at times to about 100 standard units per cubic centimeter, but never found in much larger numbers. Frequent application of small quantities of copper sulphate in a couple of small bays found to be favorite breeding places for bluegreen algae, doubtless helped materially in keeping these forms in check and prevented their spreading to other parts of the lake.

The only protozoa that were at all common at the weir where the water leaves the lake, were Ceratium, Dinobryon, Vorticella and Uroglena. The response of these forms to the copper treatment is shown in curve 4. Running from about 200 to 300 standard units per cubic centimeter at the time of the first treatment, they disappeared for about ten days. They reappeared in similar numbers before the second treatment, but after the second treatment disappeared rather suddenly and only slight traces of them occurred again during the entire season.

The vertical distribution of organisms in Vadnais Lake is a matter of interest and importance. The relative number of organisms found at different depths below the surface will of course vary a good deal, depending upon the organisms present as well as upon certain vertical currents set up in the water at certain seasons of the year, especially during the spring and autumn. When bluegreen slimes or green scums are present in large quantities, the number found at the surface would of course be greatly in excess of the number found at any point below the surface. But in a lake the size of Vadnais conditions are not favorable in the main body of


June
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October
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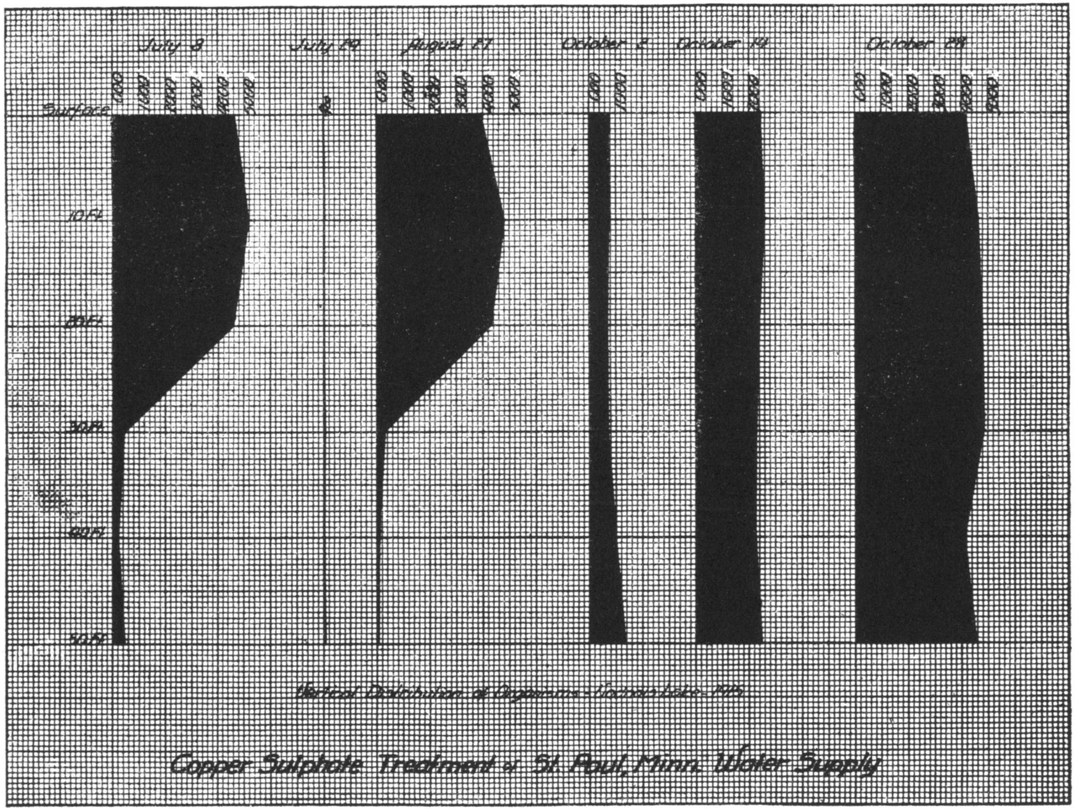
November
7
17
27
December
7
300
200
100
0
Total for all Protozoa
First Treatment
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Second Treatment
Third Treatment
Samples taken at Outlet
Vadnais Lake 1915
Total for all Cyanophyceae
Copper Sulphate Treatment of St Paul, Minn. Water Supply

CURVE 4

the lake for these surfaceloving forms. The agitation of the water even by light winds is sufficient to break up the fragile colonies of the bluegreen slimes, and liberate the gases collected in the meshes of the green scums, so that the individual plants or organisms separated from these buoyant gases settle of their own weight to depths where light is too weak and other conditions are unfavorable for growth. With many of the deep water forms, however, it is different. Such forms as Synedra, Stephanodiscus, Eudorina, Pandorina, and others, do not collect in scums at the surface, and are not greatly affected by agitation of the surface waters by the wind. They are usually more abundant a few feet below the surface than they are at the surface. The relative numbers of organisms found at various depths in Vadnais Lake on several dates during the summer and autumn of 1915 are shown in curve 5. The samples for these results were taken near the deepest part of the lake where the total depth was about 55 feet. The number of organisms here near the surface corresponded quite closely to the total number occurring at the weir on the same day. During the autumnal circulation the number was a little larger here than at the weir.

The two series of samples taken on July 8 and August 27, respectively, give perhaps the most normal vertical distribution of organisms for the summer, though at times they were much more numerous than on either of these dates. On July 8 the total number of standard units of organisms per cubic centimeter at the surface was 4656; at 10 feet below the surface, 5186; at 20 feet below the surface, 4591; at 30 feet below the surface the number dropped suddenly to 462; at 40 feet there were 222, and at 50 feet the number was 492. The relative distribution on August 27 was nearly the same as that on July 8, though the number at each level was a little smaller than on the former date. These samples were taken at a time when organisms, particularly diatoms, were increasing very rapidly. The first was taken nearly four weeks, and the second six weeks after a copper sulphate treatment. The thoroughness with which the organisms were cleaned out by the copper treatment may be seen from the samples taken on July 29, two weeks after the second treatment, and about the time when the effects of the treatment were most noticeable. These are the numbers in standard units per cubic centimeter that occurred at various depths on July 29; surface, 19; 10 feet, 34; 20 feet, 22; 30 feet, 63; 40 feet, 28; 50 feet, 60.

The three series of samples taken during the month of October


July 8
July 19
August 27
October 2
October 14
October 28
000
1000
2000
3000
4000
5000
Surface
10 Ft.
20 Ft.
30 Ft.
40 Ft.
50 Ft.
Vertical Distribution of Organisms - Vadnais Lake - 1915
Copper Sulphate Treatment of St. Paul, Minn. Water Supply

Curve 5

show the distribution of organisms during the autumnal overturning of waters in the lake. The first series taken on October 2, shortly after the circulation started, shows organisms, mostly diatoms, to be only about half as abundant at the surface as they are at the bottom. Later they become nearly uniform in their distribution from surface to bottom and probably remain so until the autumnal circulation ceases, meanwhile increasing very rapidly in numbers as they are borne to the upper strata where conditions are favorable for their growth and reproduction.

The following table gives the total number of organisms in standard units per cubic centimeter, as well as the water temperature for various depths, on the dates indicated:

DISTANCE BELOW SURFACE	JULY 8	JULY 29	AUGUST 27	OCTOBER 2	OCTOBER 14	OCTOBER 28
Surface...	4656	19	3940	759	2456	4180
	69°F.	76°F.	68°F.	59°F.	52.8°F.	50.8°F.
10 feet....	5186	34	4815	752	2602	4646
	69°F.	73°F.	68°F.	59°F.	52.7°F.	50.8°F.
20 feet....	4591	22	4338	691	2403	4798
	67.5°F.	67°F.	67°F.	59°F.	52.6°F.	50.8°F.
30 feet....	462	62	306	711	2295	4869
	62°F.	63°F.	61.4°F.	59°F.	52.5°F.	50.8°F.
40 feet....	222	28	88	996	2253	4127
	59°F.	61°F.	58.5°F.	59°F.	52.5°F.	50.8°F.
50 feet....	492	60	81	1377	2495	4581
	57°F.	59°F.	58°F.	59°F.	52.5°F.	50.8°F.

The shores of Vadnais Lake are mostly high, and the banks are rather steep, sometimes sandy, but usually of clay or clay and gravel mixed. At only two or three points in the entire shore line is the shore inclined to be low or marshy, and these low shores are very limited in extent. One of these, at the extreme eastern end of the lake, perhaps 100 yards long and 20 or 30 yards wide and extending parallel with the shore, is covered with a growth of small willows. Here the ground is flooded in the spring and after heavy rains, and pools of stagnant water may be found among the willows at almost any time during the summer. Stagnant water is always a favorable breeding place for organisms, but the particular diatoms and other organisms that were most troublesome in the main lake did not find this a favorable place, and aside from water net (Hydrodictyon) which became very abundant here at times, and gradually worked its way out into the shallow water of the lake near by, the lake water near here did not contain a larger number of organisms than at other points along the shore.

A second low shore, more troublesome than the first, is found on the northeast side of the lake, about opposite the gate house. Here a small stream enters the lake through a very small meadow. Between this little meadow and the lake a ridge has been formed, in part by silt and sand carried down by the stream, but largely perhaps by the crowding of ice sheets from the lake. Back of this ridge is a shallow bay, some 200 yards long and 20 or 30 yards wide. This bay is very shallow, varying from the frequently exposed mud flats to a maximum depth of not more than 2 or 3 feet. It lies parallel to the shore line of the lake and opens into the lake near one end through a channel 8 or 10 yards wide. The little stream flows diagonally through one end of this bay, entering the lake through the channel just mentioned. The main part of the bay is perfectly stagnant, and being so very shallow reaches a very high temperature on a warm summer day. It is an ideal place for the growth and reproduction of many algal forms, including Spirogyra and Hydrodictyon which form a scum on the surface. Besides these there are also many smaller, less conspicuous forms such as Diatoms, Volvox, and several of the bluegreen algae, including Nostoc and Gloeotrichia. In certain shallow parts of the bay the bottom is very soft, a muck from 3 to 5 feet in depth not being at all uncommon. When the water is low, much of this area may be covered with a very shallow layer of water, or even completely exposed. In such places numerous organisms accumulate and form dense slimes and heavy scums that give off disagreeable odors and tend to pollute the lake, especially when flushed out into the open water by surface drainage after a heavy shower. On account of the extreme shallowness of the water here, the distribution of copper sulphate by towing a sack of the crystals behind a boat was impracticable. Often considerable areas could not be reached by the boat at all. The abundant dead organic matter, and the mud stirred up by the boat apparently absorb much of the copper and prevent it from spreading any great distance from the path of the boat. The result was that in many places only a few feet from the path of the boat where copper sulphate was dissolved, the scums and slimes continued to grow and reproduce as if no treatment had been given. To overcome unfavorable conditions encountered here the spray pump was resorted to and proved to be a most satisfactory and successful means of treating such inaccessible places. The type of pump used was a small hand pump such as is used for washing windows or spraying trees. When used without the spraying nozzle a stream could be thrown 50 feet and many small areas inaccessible by boat were easily reached and thoroughly freed from organisms by a single treatment. The spray pump was also found to be very effective and economical in treatment of green scums such as water net (Hydrodictyon), Spirogyra, and similar forms often accumulating near the shore of quiet or protected bays.

Of the entire shore line, however, the most favorable breeding place for bluegreen slimes is a small shallow bay in the mouth of the inlet, at the extreme north end of the lake. The inlet is about 15 feet wide but when it approaches to within about 200 yards of the lake, it broadens out into a shallow bay, some 50 yards wide. The main channel here is 3 or 4 feet deep and usually has quite a perceptible current, but at either side is shallow and sluggish, and is a favorable place for growth of pond weeds and water lilies, as well as for microscopic organisms. Just before this inlet bay opens out into the main lake, a sandy point juts out from the eastern bank to the edge of the main or deeper channel. On the opposite or western side of this inlet, a very shallow arm of the bay extends westward about 100 yards parallel with the lake shore, being separated from the main lake by a low point. This forms a favorable pocket into which the bluegreen slimes and other surface forms coming in from untreated lakes above, easily drift, especially when there is a slight breeze from the south or east. Here, on account of the warm quiet water, they multiply very rapidly, and constant attention was required here to prevent their spreading to other parts of the lake. On June 16, organisms were found to be quite abundant here. Two samples, one from the middle of the bay and the other from near one side where organisms were evidently more abundant, were examined under the microscope. The first of these showed 2290 and the second 5810 standard units of organisms per cubic centimeter, largely due to green algae. During several days following, the bluegreen algae drifted in from the inlet and a heavy scum accumulated. By June 23 this scum practically covered the entire bay. On this date about 20 pounds of copper sulphate were introduced here. As to the

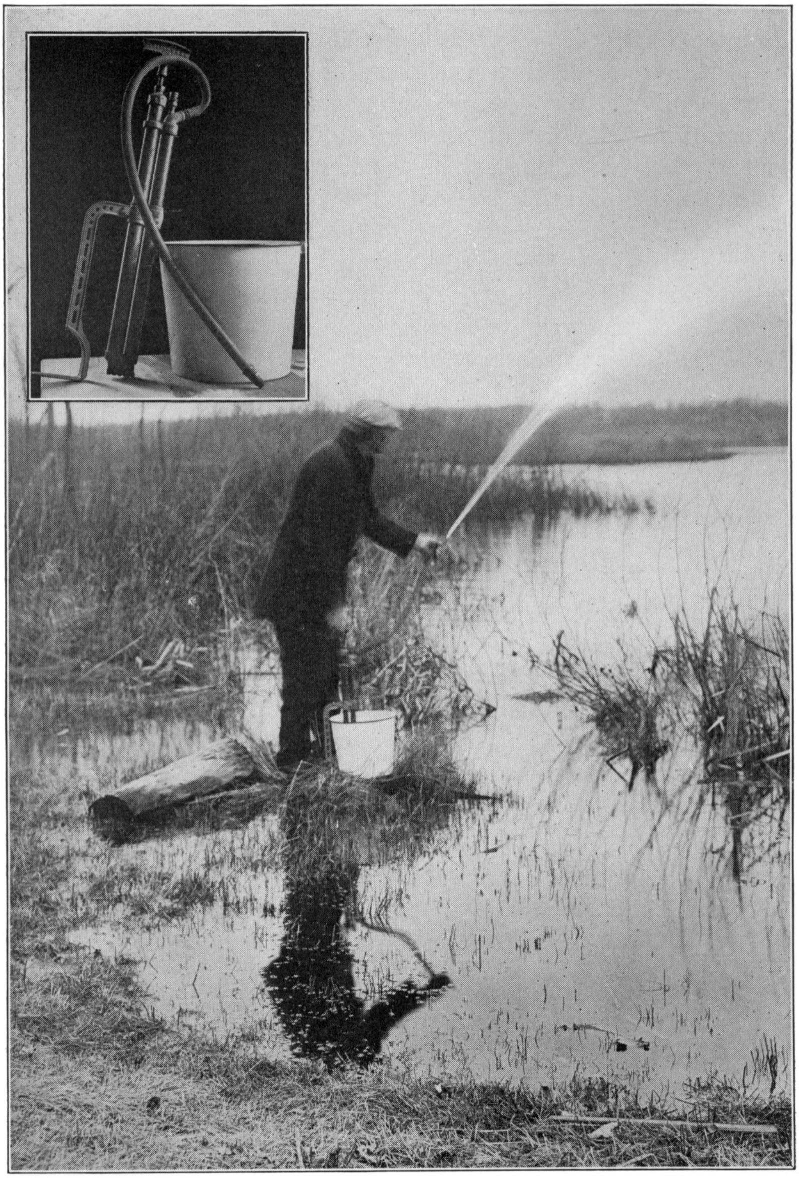
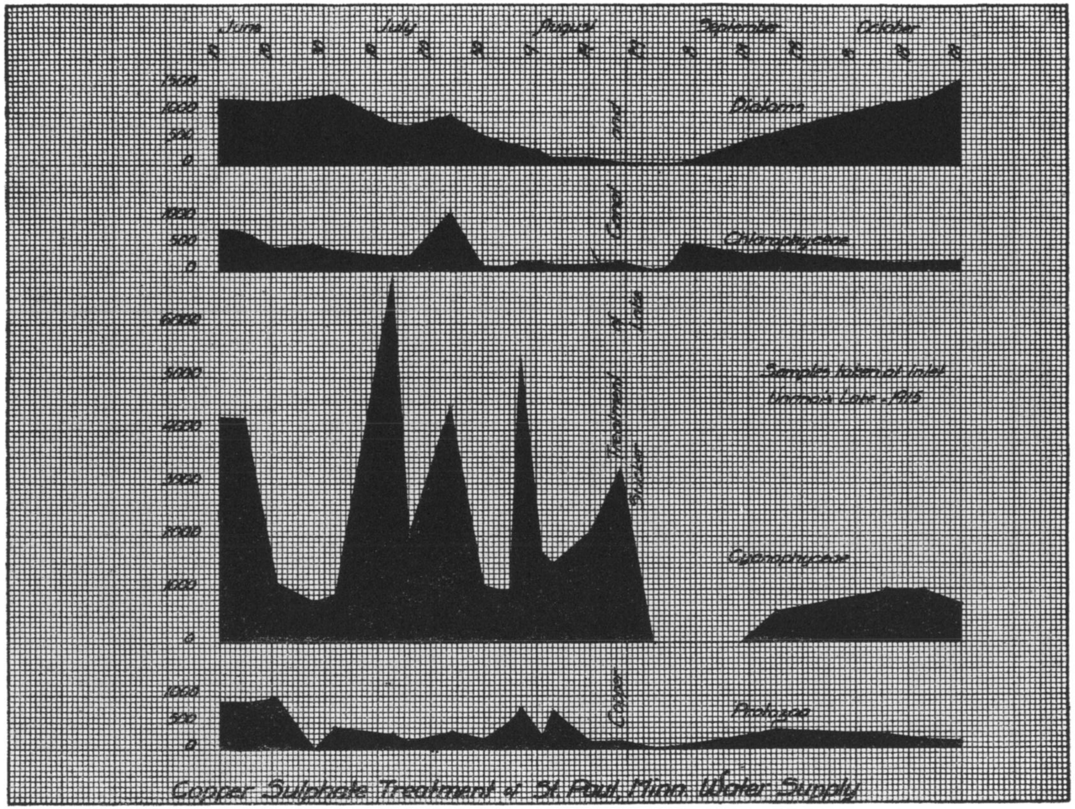


FIG. 5. SPRAY PUMP TREATMENT

strength of this treatment it is difficult to say, but it was several times heavier than that given the lake nine days before. In two days time not a living alga could be seen in the entire bay. A slight odor due to decaying algae was present, the water while much clearer than it had been before, had a dark color. A microscopic examination failed to show a single algal form present, where two days before there had been several thousand for every cubic centimeter of water. Three forms of protozoa were present in small numbers, but their entire total amounted to only 116 standard units per cubic centimeter, and the amorphous matter suspended in the water was only a small per cent of what it had been a few days before. For about four weeks following this treatment the water here remained clear and comparatively free from organisms, but late in July the bluegreen forms drifting in from the inlet began to show up in great quantities. On July 30 a sample showed more than 40,000 standard units per cubic centimeter, mostly bluegreen algae that had drifted in from the mouth of the inlet. About 25 pounds of copper sulphate introduced at this time cleaned out the algae in three or four days. Great quantities of these organisms were constantly drifting in from the inlet and within a week or so began to accumulate again. A sample taken August 4 showed 700 standard units per cubic centimeter. Another sample taken August 6 showed 51,000 standard units per cubic centimeter. The following day another treatment of 25 pounds of copper sulphate was given the little bay. In two or three days the bay was again free from living organisms. Microscopic examination of the water here was not made again until August 20, but on that date there were but 286 standard units of organisms per cubic centimeter. The water here remained practically free from algae the remainder of the season.

In general the shore line of the lake is very regular, and aside from the three small places above described, there are no stagnant bays or other places along the shore where pond scums and bluegreen slimes find a favorable breeding place. The size and depth of the lake, the high clean shores and the regularity of the shore line all contribute to its adaptability as a reservoir, for which purpose it is used. The control of microörganisms in a lake of this size is quite a problem. Were the lake fed entirely by underground springs it might be less difficult, but Vadnais Lake is supplied by water from a chain of several lakes, some of them of considerable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1500
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Diatoms
1000
500
0
Chlorophyceae
6000
5000
4000
3000
2000
1000
0
Samples taken at Inlet
Vadnais Lake - 1915
Cyanophyceae
1000
500
0
Protozoa
Copper
Sulphate
Treatment
of
Canal
and
Lake
Copper Sulphate Treatment of St. Paul, Minn. Water Supply

CURVE 6

size and depth, but many of them small, shallow and with low muddy shores and weedy bottoms. The water of these low shores and shallow bays reaches a very high temperature during the summer, and many organisms, especially several of the bluegreen slimes, multiply here with great rapidity. With the change of winds they drift about and if once carried out into the open lake may be picked up by the sluggish currents and borne down to Vadnais Lake, and thence to the city water mains.

The number of organisms entering Vadnais Lake through the waters of the inlet is enormous (curve 6). During the greater part of the summer, the number of algae entering here averaged more than 4000 standard units per cubic centimeter of water, and with 10,000,000 to 15,000,000 gallons of such water entering every day, it is not difficult to see why several treatments were necessary to keep down the number of organisms at the intake for the city water system. The diatoms and many of the green algae entering here spread throughout the lake, multiplying and increasing rapidly everywhere. For them the deep water offers ideal conditions for growth and reproduction. They move slowly down the lake, dividing and reproducing as they go, and by the time they have reached the gate house, some have increased an hundred or even a thousand fold. Their distribution throughout the entire lake, not merely at the surface, but from the surface to a depth of about 25 feet, makes it possible to control or destroy them only by a treatment of the entire lake.

With the bluegreen algae, however, it is very different. They flourish best near the surface, and prefer the warmer, quieter waters of the shallow bays. Here under favorable conditions they increase with astounding rapidity, some forming a dense scum upon the surface of the water, others suspended near the surface, give a decided bluegreen color to the water, and may be quite uniformly mixed to a depth of several inches below the surface. Should they remain in these breeding places they would perhaps give little cause for alarm. But under certain conditions they may become quite troublesome. A gentle breeze from the right direction sweeps them out into the main lake. If the water of the lake is a little rough, the fragile colonies or masses of the bluegreen forms are broken to pieces, they disintegrate, and in one or two days the lake may be almost completely free from them. Should the weather be calm, however, with just enough breeze to carry the slimes and spread them over the surface of the lake, but not sufficiently rough to break them up, a bluegreen bloom may develop over the entire surface of the lake, and may accumulate into a definite scum on the leeward side of the lake. A disagreeable odor is usually given off wherever these forms are found in such great abundance. The control of bluegreen algae in a lake like Vadnais, does not seem to be especially difficult. All of these forms that are inclined to be troublesome are exceedingly sensitive to copper sulphate. Whenever they have accumulated in a given locality, in sufficient quantities to be noticeable to the unaided eye, an application of a little copper sulphate to the water will prove very effective. The one part of Vadnais Lake that required constant attention to prevent the spread of these bluegreen slimes was the shallow bay at the mouth of the inlet. Not only was the bay an ideal breeding place for these organisms, but it was being continually replenished by a stream laden with these and other organisms. As stated above, the water entering here contained for the greater part of the summer an average of more than 4000 standard units of organisms for every cubic centimeter of water. Of these 4000 standard units about 2500 belonged to the bluegreen group. On account of the constant change of water in this bay the effects of the copper were not so enduring as in the more stagnant bays, and it was found necessary to treat here about every ten days to prevent accumulations of the bluegreen scums in the stagnant water along the sides of the channel where the inlet opens out into the lake. The effectiveness of these treatments, however, may readily be seen by a comparison of the chart (curve 6) showing the number of bluegreen algae here, with the one (curve 4) showing the number at the weir below the gate house. On June 14, the day when the first copper treatment was given the lake, the number of bluegreen algae in the sample taken at the weir, showed 1780 standard units per cubic centimeter of water. In about ten days they had dropped to 200 standard units per cubic centimeter, and about July 20 disappeared entirely. From that time to the end of the season, these organisms were almost completely absent from the waters of the weir, though late July and August is the very time when they should have been most abundant. At the inlet they continued to pour in, their numbers ranging from 2000 to 6000 standard units per cubic centimeter until August 27 when a heavy copper treatment given the canal and Sucker Lake above Vadnais put a stop to their entrance here for a couple of weeks.

After this the cool weather of late September and October kept them in check and they did not rise above 1000 standard units per cubic centimeter the remainder of the season.

In order to get a better idea of the effect of copper sulphate upon the various organisms found in Vadnais Lake it may be well to compare the numbers of some groups entering the lake at the inlet (curve 6) with those in the water leaving the lake as indicated by figures 1 to 4. The two most abundant forms in Vadnais Lake, namely Synedra pulchella and Stephanodiscus niagarae, are forms that prefer the deep water, and while they enter the lake in small numbers, the explanation for the very large number occurring at times in Vadnais Lake is to be sought in the conditions existing in this lake, favorable to their growth and reproduction, rather than to any large number that may be found pouring into the lake at any one time through the inlet.

Of the four groups of organisms entering the lake, the Cyanophyceae or bluegreen algae are usually most numerous, and appear to be, as a group, most sensitive to the copper sulphate. For about ten weeks during the summer they ran from 1000 to 7000 standard units per cubic centimeter at the inlet, with an average for this period of about 2500 standard units per cubic centimeter. At the outlet of the lake they were running about 2000 standard units per cubic centimeter at the beginning of this period, but after the first treatment, they rapidly disappeared and during the last six weeks of this period scarcely a trace of them was found. On August 27, at the time of the third treatment of Vadnais Lake, the creek entering the lake, and Sucker Lake, a small lake a short distance above Vadnais, were treated, and for the first time during the summer the organisms practically disappeared from the waters of the inlet. Although the treatment here was considerably heavier than in Vadnais Lake, the effects were of shorter duration, for the smaller size of Sucker Lake and creek, permits a more rapid displacement of the treated water, by untreated water from above.

From June 10 to August 27 the average number of organisms in the inlet of Vadnais Lake, was more than 4000 standard units per cubic centimeter. Compare these figures with the number found in the samples taken at the weir below the gate house, especially for a period of about five or six weeks following the copper sulphate treatments of the lake, when the number here was below 100 standard units per cubic centimeter, and the effectiveness of a treatment of 1 to 10,000,000 can not be questioned.

While many organisms appeared at one time or another during the summer in the waters of Vadnais Lake, and disappeared, probably as a result of the copper treatment, many of them were not found in sufficiently large numbers to justify a statement concerning the exact effect of copper sulphate upon their existence. With several others, however, that were more common there can be no question as to the effect of copper sulphate. The following forms were found before one or more of the treatments in sufficient numbers to justify certain conclusions concerning the effects of the treatment as here given:

Chlorophyceae. (Green Algae)
    Spirogyra sp.
    Eudorina elegans Ehr.
    Pandorina morum (Mull.) Bory.
    Pediastrum duplex Meyen.
    Staurastrum sp.
Diatomaceae. (Diatoms)
    Stephanodiscus niagarae Ehr.
    Synedra pulchella (Ralfs.) Kg.
    Fragilaria capucina Desmaz.
    Asterionella formosa Hass.
    Cyclotella comta (Ehr.) Kg.
    Melosira granulata (Ehr.) Ralfs.
Cyanophyceae. (Bluegreen Algae)
    Anabaena oscillarioides Bory.
    Anabaena flos-aquae (Lyngb.) Breb.
    Clathrocystis aeruginosa (Kuetzing) Henfrey.
    Coelosphaerium Kuetzingianum Haegeli.
    Aphanizomenon flos-aquae (Linn.) Ralfs.
    Rivularia echinulata (Smith) Born. and Flah.
Protozoa. (Animal Forms)
    Ceratium longicorne Carter.
    Dinobryon sertularia Ehr.
    Uroglena volvox Ehr.
    Vorticella communis Ehr.

From observations made on above mentioned forms, the results of which are for the most part shown in accompanying diagrams or figures, the following conclusions may be drawn:

1. With conditions under which above treatments were made, the use of one part of copper sulphate in 12,000,000 parts of water is quite adequate for the elimination of Spirogyra, Cyclotella, and most of the Cyanophyceae. It will practically eliminate Melosira and the four protozoa here listed; for the other forms above mentioned it will bring about great reduction but may not eliminate them.

2. The use of 1 part of copper sulphate in 10,000,000 parts of water is effective in practically eliminating all forms mentioned in above list, with the possible exception of Eudorina and Pandorina, and with the conditions under which the treatments were made this amount is entirely adequate for their suppression.

3. With conditions under which above treatments were made, a treatment of one part of copper sulphate in 10,000,000 parts of water remains effective for about five weeks, after which time the organisms present, or many of them at least, seem to find conditions favorable for their growth and reproduction, and if the treatment is not repeated at this time they may increase again with remarkable rapidity.

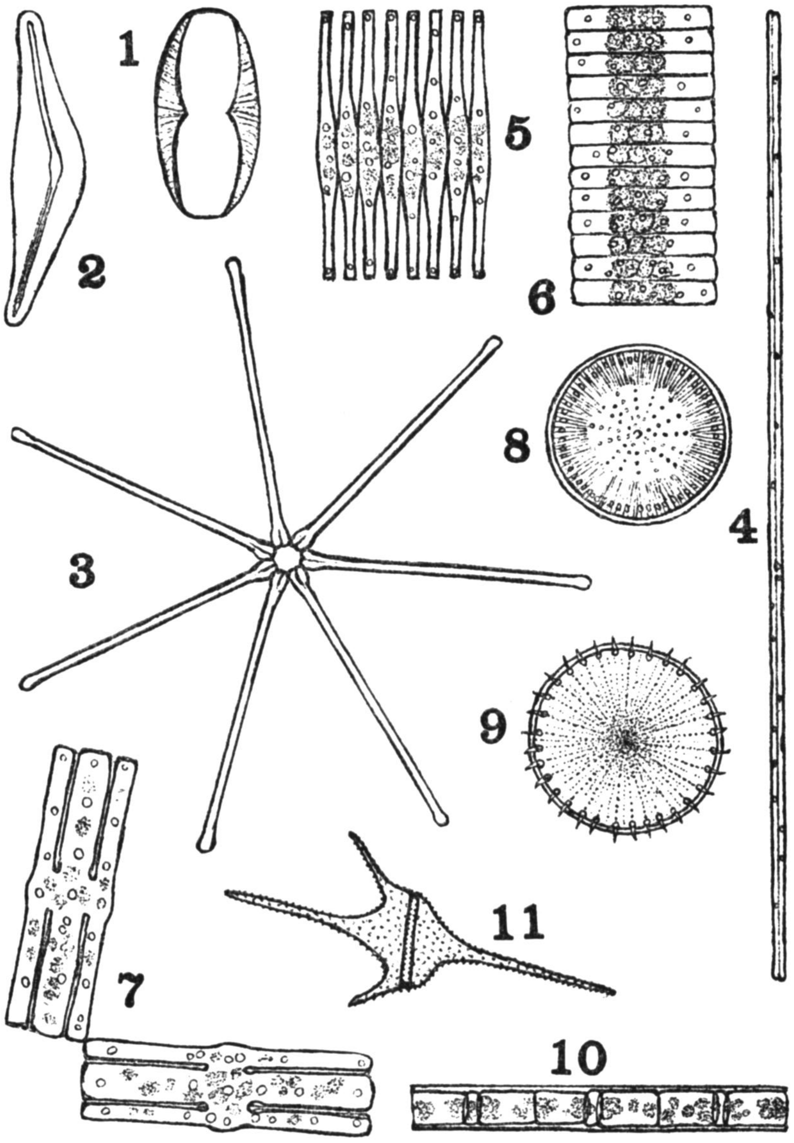
4. Where quiet shallow bays afford breeding places for numerous organisms, or where any one or more organisms become abundant in small or limited areas, local treatment, or the application of small quantities of copper sulphate to the particular spot where the trouble is originating, has been found very effective. If careful attention is given to such areas, and accumulations of organisms prevented here, the number of general treatments necessary to keep the lake clean for the entire season may be lowered and the total cost of treatments materially reduced.

5. For treatment of very shallow bays, flat muddy shores and small ponds the use of a hand pump such as is used for spraying trees is a practicable and economical means of distributing copper sulphate. In addition to spreading the solution in places inaccessible for a boat, this method has the advantage of leaving the water unroiled and gives the organism the full effect of the copper, much of which might otherwise be absorbed by mud and organic matter stirred up by a boat in such places.

EXPLANATION OF PLATE I

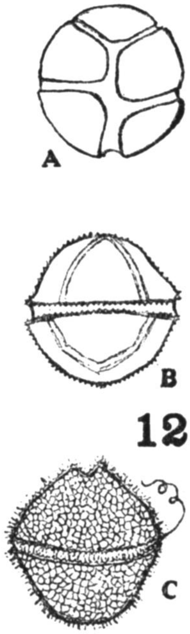
1. Amphora ovalis (Bréb.) Kg.
2. Cymbella lanceolata (Ehr.) Kirchn.
3. Asterionella formosa Hass.
4. Synedra ulna (Nitzsch.) Ehr.
5. Synedra pulchella (Ralfs.) Kg.
6. Fragilaria capucina Desmaz.
7. Tabellaria fenestrata Lyngb. Kg. var. intermedia Grün.
8. Cyclotella comta (Ehr.) Kg.
9. Stephanodiscus niagarae Ehr.
10. Melosira granulata (Ehr.) Ralfs.
11. Ceratium longicorne Carter.

ORGANISMS FOUND IN VADNAIS LAKE PLATE I



Explanation of Plate II

12. Peridinium tabulatum Ehr.
13. Anabaena flos-aquae (Lyngb.) Bréb.
14. Lyngbya majuscula Harv.
15. Coelosphaerium kützingianum Naeg.
16. Merismopedia glauca Naeg.
17. Nostoc sp.
18. Anacystis marginata Menegh.
19. Pandorina morum (Muell.?) Bory.
20. Eudorina elegans Ehrenb.
21. Gloeocystis gigas (Kg.) Lagerh.



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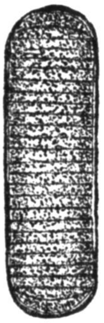

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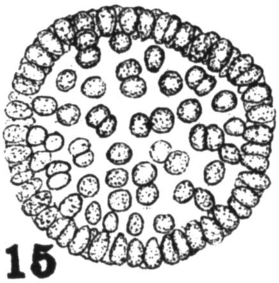

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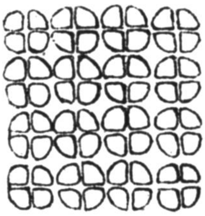

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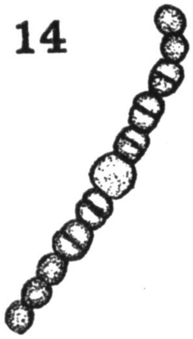

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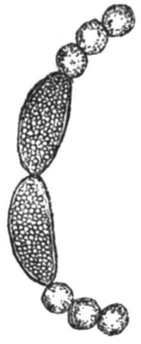

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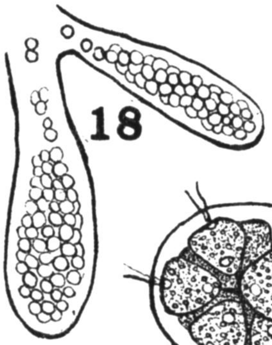

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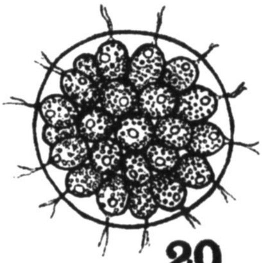

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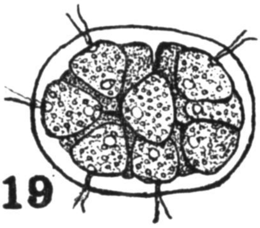

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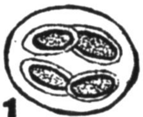

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EXPLANATION OF PLATE III

22. Rhaphidium polymorphum Fresen. var. falcatum (Corda) Rabenh.
23. Rhaphidium polymorphum Fresen. var. aciculare (A. Br.) Rabenh.
24. Dictyosphaerium pulchellum Wood.
25. Nephrocytium agardhianum Naeg.
26. Scenedesmus quadricauda (Turp.) Bréb.
27. Scenedesmus bijugatus (Turp.) Kg.
28. Staurastrum paradoxum Meyen. var. longipes Nordst.
20. Staurastrum sebaldi Reinsch.
30. Arthrodesmus incrassatus Lagerh.
31. Staurastrum minneapoliense Wolle.
32. Pediastrum duplex Meyen.
33. Pleurotaeniopsis quaternaria (cordst.) De Toni.
34. Micrasterias truncata (corda) Bréb.
35. Cosmarium nitidulum De Not.
36. Closterium parvulum Naeg.
37. Coelastrum microporum Naeg. var. speciosum Wolle.

ORGANISMS FOUND IN VADNAIS LAKE PLATE III